Efficiency evaluation of phosphor-white high power light-emitting diodes

A. Keppens[1,2], P. C. Acuña[3], H. T. Chen[4], G. Deconinck[2], P. Hanselaer[1,2]

[1] *Light & Lighting Laboratory, Catholic University College Gent, Gebroeders Desmetstraat 1, B-9000 Gent, Belgium*

[2] *ESAT/ELECTA, K.U.Leuven, Kasteelpark Arenberg 10, B-3001 Leuven, Belgium*

[3] *LABE, National University of Colombia, Carrera 30 - 45, 03 Bogotá, Colombia*

[4] *Fujian Engineering Research Centre for SSL, Xiamen University, Siming South Road 422, Xiamen, China*

Contact: arno.keppens@kahosl.be

ABSTRACT

High power light-emitting diode (LED) efficiency is strongly dependent on the device type and on operating conditions. Electrical and optical power measurements are therefore performed on a selection of phosphor-white LEDs at a number of currents and temperatures. The results allow for a comparative evaluation of their dominant loss mechanisms.

EXPERIMENTS

Five commercial phosphor-white high power LED packages, indicated as L1 to L5, have been selected for investigation through various current-voltage and spectral radiant flux measurements. Forward current-voltage characteristics at different junction temperatures have been determined by placing the LEDs in a Heraeus UT6 isothermal oven with active air circulation. The predefined oven temperatures (300, 320, 340, and 360 K) have been precisely measured with a PT100 thermistor. In order to avoid junction heating during measurement, a Keithley 2440 5A SourceMeter was pulse-operated by a LabVIEW 7.1 program.

Spectral radiant flux measurements at different currents and junction temperatures have been performed with a custom-made integrating sphere [1]. The LEDs were attached to the sphere surface using an aluminium mounting plate incorporating a Peltier element and PT100 thermistor. The Peltier element regulates the plate temperature until the LED junction temperature – determined by a forward voltage measurement [2] – shows the desired value.

RESULTS AND DISCUSSION

The measurement equipment described above allows determining the LED input power P_{in}, power loss into the internal series resistance ΔP_R, external quantum loss ΔP_{EQ}, Stokes shift power loss ΔP_S, eye sensitivity loss $\Delta P_{vis} = \Phi_{e,\lambda}\left(1 - \mathrm{V}_\lambda\right)$ and luminous flux Φ [3]. All these quantities can be determined independently and are connected by the following equation, which was also used to verify the measurement results:

$$P_{in} = \Delta P_R + \Delta P_{EQ} + \Delta P_S + \Delta P_{vis} + \Phi \big/ \left(683\ \mathrm{lm} \cdot \mathrm{W}^{-1}\right) \tag{1}$$

At first, the current and junction temperature dependence of each power loss has been examined at 300 K junction temperature and a 350 mA drive current, respectively (see Fig. 1).

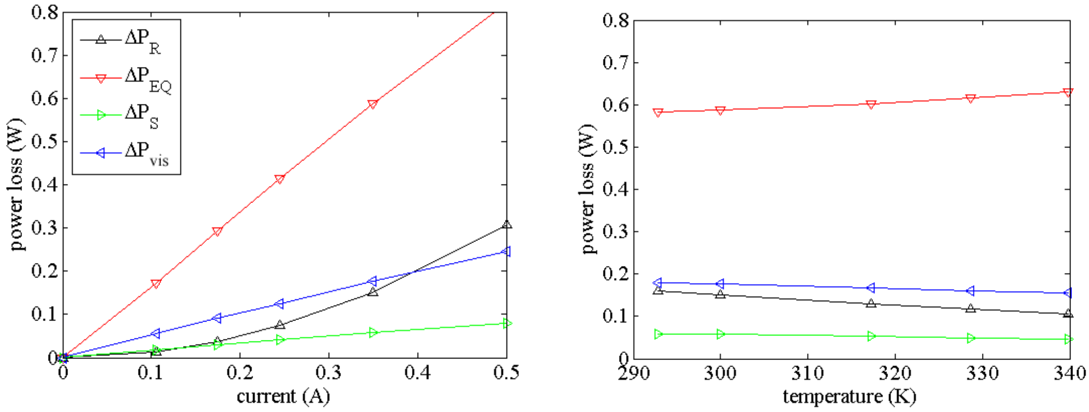

FIG. 1. Power losses as a function of current at 300 K (left), and temperature at 350 mA (right) for LED L1.

With increasing current, the quantum, Stokes and visual losses increase quasi linearly. This means that the quadratic increase of the power loss into the internal series resistance forms the main reason for the decreasing diode efficiency with increasing current. On the other hand, the decreasing diode efficiency with junction temperature is only due to the increasing external quantum loss with increasing temperature, as other losses slightly decrease.
Secondly, all five terms on the right-hand side of Eq. (1) have been compared for all LEDs at normal operating conditions (350 mA and 330 K junction temperature) and per watt input power (see Fig. 2). This way, the last term multiplied with 683 (lm/W) equals the luminous efficiency. From the data in Fig. 2, it is clear that the internal series resistance directly consumes about 10 to 20 % of the initial input power. As a result, the overall efficiency is remarkably higher for LEDs with a reduced resistance (e.g. L1). External quantum loss is clearly the dominant loss factor and can be related to the colour temperature of the LEDs. Indeed, L1 and L2 are cool white devices and exhibit the smallest quantum losses. L3 is neutral white, while L4 and L5 are warm white. Non-fluorescent absorption in the phosphor seems to be more important for these warm white LEDs. Also from Fig. 2, the luminous flux is found to be correlated to the external quantum loss. For this reason, the LED efficiency is always higher for cool white LEDs [4]. The Stokes shift losses equal about 5 % of the input power for all measured LEDs. Although the conversion loss per photon is larger for warm white LEDs, this effect is compensated by the smaller number of emitted photons. The remaining luminous flux part is always a few percent smaller than the visual loss for phosphor-white LED spectra.

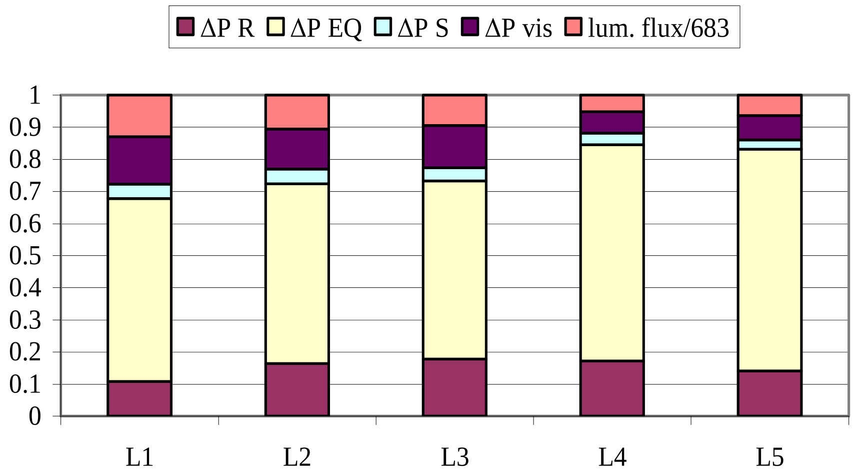

FIG. 2. Comparison of normalised power losses and flux for all LEDs at 350 mA and 330 K.

CONCLUSIONS

Different power loss mechanisms present in phosphor-white high power LEDs have been evaluated at different operating conditions and mutually compared. Power loss in the internal series resistance has been found to amount 10 to 20 % of the initial input power and is the main reason for the decreasing diode efficiency with increasing current. External quantum loss is clearly the dominant loss factor and can be related to the colour temperature of the LEDs. This quantum loss is also responsible for the efficiency decrease with junction temperature.

REFERENCES

[1] P. Hanselaer, A. Keppens, S. Forment, W. R. Ryckaert, and G. Deconinck, “A new integrating sphere design for spectral radiant flux determination of light-emitting diodes (LEDs),” Meas. Sc. & Tech. 20, 095111 (2009).

[2] A. Keppens, W. R. Ryckaert, G. Deconinck, and P. Hanselaer, “High power light-emitting diode junction temperature determination from current-voltage characteristics,” J. Appl. Phys. 104, 093104 (2008).

[3] M. R. Krames, O. B. Shchekin, R. Mueller-Mach, G. O. Mueller, L. Zhou, G. Harbers, and M.G. Craford, “Status and future of high-power light-emitting diodes for solid-state lighting” IEEE J. Disp. Tech. 3, nr. 2, 160-175 (2007).

[4] E. F. Schubert, “Light-emitting diodes – second edition,” Cambridge University Press (2006).